Progress Notes 3616592C

Disponible également en français

No. 151, January 1985

Comparison of survey techniques for burrow-nesting seabirds

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Abstract

The accuracy and efficiency of four survey methods (quadrat, transect, point-centred quarter, and Batcheler's) are compared in two colonies of burrow-nesting seabirds. Plots and transects oriented parallel to the shoreline were more variable than those oriented perpendicularly. Small plots provided a more precise estimate of burrow density than large plots for a similar sampling effort (total area sampled). Systematic sampling yielded more precise estimates than random sampling. Both plotless techniques over-estimated the density of burrows in one area and showed no significant difference in the other. Estimates derived from quadrats and transects were more accurate than those obtained from the point-centred and Batcheler's methods.

Introduction

Literature on sampling techniques for burrow-nesting seabirds is scarce. Nettleship (1976) summarized a few techniques used to survey seabirds in arctic and eastern Canada, and proposed the use of quadrats and transects to estimate burrow density. In the course of various seabird projects along the coast of British Columbia, we gathered incidental data on the efficiency of various sampling techniques. In view of the shortage of literature, we present our preliminary findings in the hope that these will help future surveys and encourage research in this area. We collected the data with three goals in mind: first, to look at plot variability as a function of plot size and orientation; second, to compare the relative efficiency of random and systematic sampling schemes; and third, to look at the relative performances of plot and plotless techniques.

Study area

We collected the data on two seabird islands in British Columbia. Pine Island, in the Queen Charlotte Strait, harbours a breeding colony of Rhinoceros Auklets estimated at 15 000 pairs (Campbell 1976). It is a forested island, and birds breed on slopes with sparse undergrowth, which facilitated our finding the burrows. Triangle Island, in the Queen Charlotte Sound 30 km from the northwest tip of Vancouver Island, supports a colony of Cassin's Auklets estimated at 359 000 pairs (Vermeer *et al.* 1979). The island is devoid of trees and is characterized by steep talus slopes covered with different communities of herbaceous vegetation (see Vermeer *et al.* 1979 for a detailed description of habitat). The field work was done in 1979 and 1982.

Methods

We compared the accuracy (how close the estimate was to the real value) and the precision (how variable was the estimate) of four sampling techniques. Two were plot techniques — quadrats and transects, and two were plotless — the point-centred quarter method (Cottam and Curtis 1956, Mueller-Dombois and Ellenberg 1974) and Batcheler's method (Batcheler 1971, 1973). On Pine Island, we established a sampling grid of 40 m x 40 m, divided it into contiguous 2 m x 2 m quadrats, and counted the number of burrows in each quadrat. This grid was used as our sampling universe, within which we could study and compare various sampling schemes, allowing us to look at: (1) the relative efficiency of different quadrat sizes, (2) the effect of plot and transect orientation on the variability of resulting estimates, (3) the relationship between the plot and plotless techniques, and (4) the relative precision of random, systematic, and stratified sampling designs.

Further, to study the effect of transect orientation on precision in another portion of the Pine Island colony, we established 13 transects of 1 m x 50 m parallel to the shoreline, and six transects of 1 m x 150 m perpendicular to the shoreline in the same way. Similarly, we compared the plot and plotless techniques in two other sections of the colony. On Triangle Island, we compared the quadrat, transect, and Batcheler's methods in five different habitats.

Burrow densities were high in all areas sampled. The fact that burrows were easy to locate minimized observers' biases. Also, all measurements from the grid and from the parallel perpendicular transects were made by a single observer to further reduce any observers' effects. However, on Triangle Island several observers participated in the measurements, which may have increased the variability of the results.

Estimation procedures

For plot methods, we considered three sampling designs: random, systematic, and stratified with one quadrat per stratum. We calculated the variance of the estimated burrow density for random sampling by using equation (2.8) in Cochran (1977); and for stratified sampling, equation (5.6) in Cochran (1977). For systematic sampling, we calculated the estimates of burrow density for all possible random starts and then computed their variance.

We compared the various plot methods by determining what precision could be obtained for a given level of effort. In the sampling schemes, the effort, E, can be roughly divided into three components:

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$$E = E_1 + E_2 + E_3$$

where E_1 = effort required to find and count burrows,
E_2 = effort required to set up and delineate plots,
E_3 = effort required to move from one plot to the next and locate it.

E_1 is proportional to the total area of all the plots. E_2 is also approximately proportional to the total area, as large plots must be subdivided into many small ones to aid the counting procedure. In our study, we sampled an entire 40 m × 40 m grid of 2 m × 2 m plots, hence movement between plots and set-up time for plots would not be the same as if only one sample were done. However, experience indicates that in the terrain surveyed, E_3 was small with respect to E_1 and E_2. Hence it follows that total effort, E, will be proportional to the total area sampled.

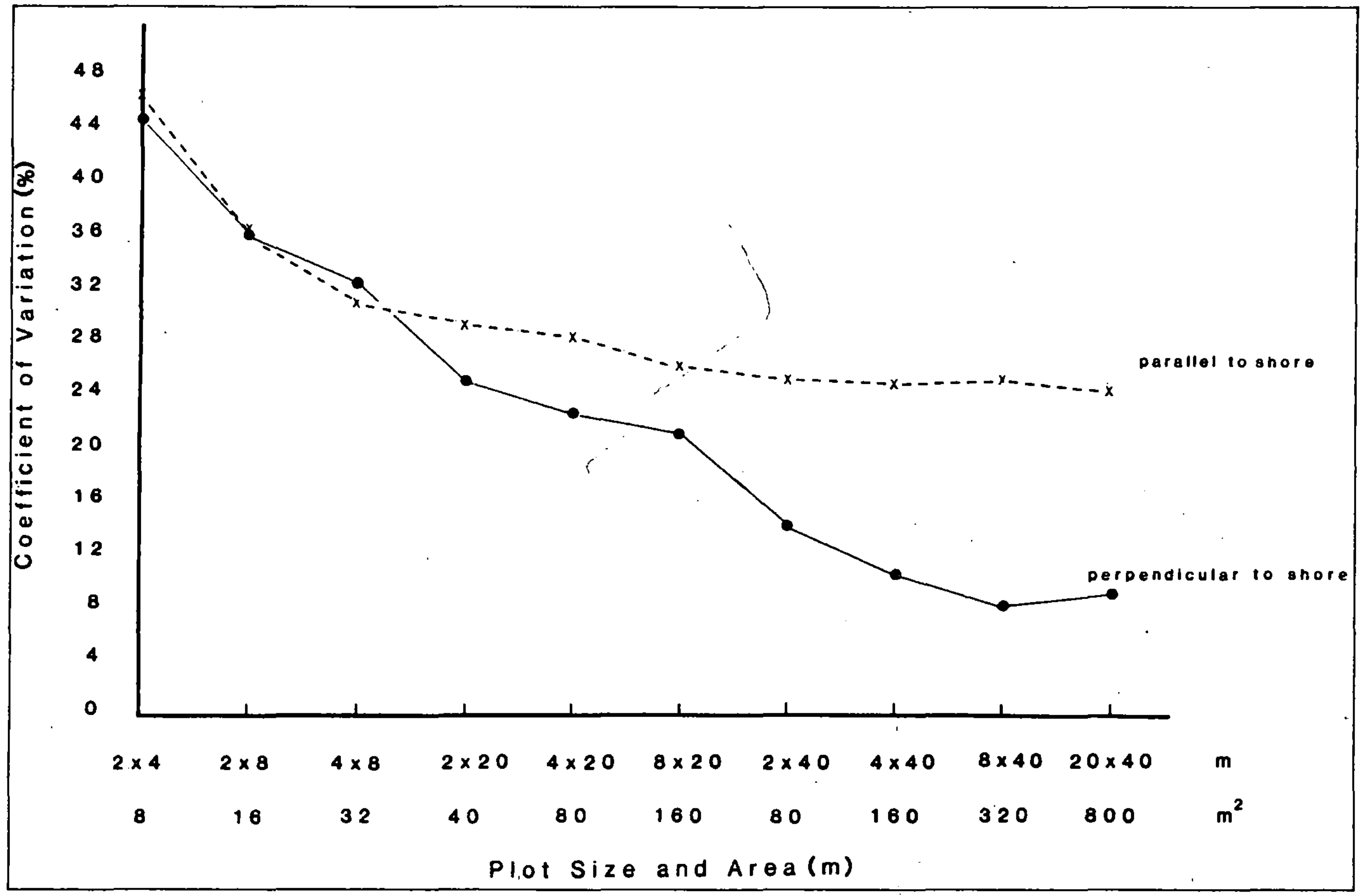
The analysis was done on a Decision 1 microcomputer with programs written in BASIC. For the two plotless methods the estimates and their precision are given in Mueller-Dombois and Ellenberg (1974) and Batcheler (1971).

Results

Plot variability in relation to orientation

Plots oriented parallel to the shoreline were more variable than those oriented perpendicularly (Fig. 1). The longer the plot, the greater the difference. Transects showed similar differences (Table 1).

Figure 1
Plot variability in relation to size and orientation

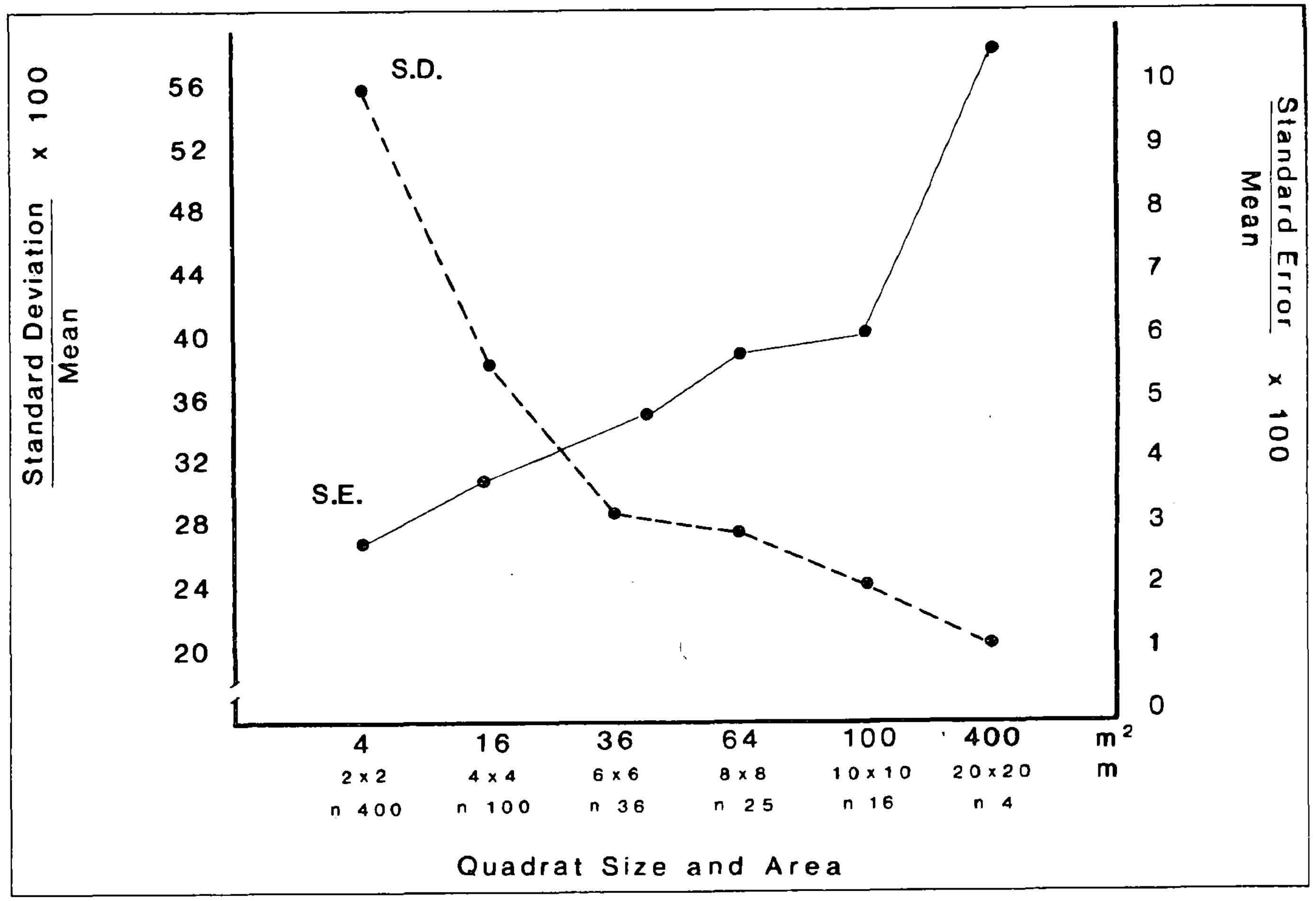


Plot variability in relation to size

Large plots were less variable than small ones (Fig. 2). However, for a similar sampling effort (total area sampled) small plots provided a more precise estimate of burrow density. The greater variability of the small plots was more than compensated for by the greater sample size obtained when censusing a given area; i.e. an area of 1600 m^2 can contain 400 plots of 4 m^2 compared with only 16 plots of 100 m^2.

The sampling effort (as measured by the size of the area sampled) required to detect a given change in burrow density is less with small plots than with large plots (Table 2). To determine the effort necessary, we set the type I error (the probability that the data will show a change when there is none) at 0.05, and the type II error (the probability that a change will not be detected when it exists) at 0.10. Table 2 shows the effort required to detect changes of 10, 20, and 30%, and compares it with the effort required for 95% confidence limits (type I error of 0.05) on the estimate to be within 10, 20, and 30% of the estimated density. For example, to detect a given change in the number of burrows, it is necessary to sample an area twice as large with 16 m^2 quadrats as one with 4 m^2 quadrats. The methods for estimating sample sizes are described in Eberhardt (1978) and section 4.13 of Snedecor and Cochran (1967).

Figure 2
Plot variability in relation to quadrat size



Comparison of systematic, random, and stratified sampling with one observation per stratum

For this comparison, we proceeded as follows. First we combined the data into a given quadrat size (2 x 2, 4 x 4, etc.). Then we chose a rectangular block, say R quadrats deep (perpendicular to the shore) by C quadrats wide (parallel to the shore), and calculated the variance for:
(1) a systematic design where the sampling interval was R quadrats deep and C quadrats wide, i.e. the sampling fraction was $1/RC$;
(2) a stratified sample (one unit per stratum) where each stratum was R quadrats wide and C quadrats deep; and
(3) a random sample with sampling fraction $1/RC$.
Then for each possible value of R and C we computed the variances corresponding to the three designs. To obtain a feeling for the relative precision of the three procedures, a "variance index" was formed for each R and C by multiplying the variance corresponding to each sample design by 100/(the sum of the three variances). Thus the sum of the three indices is 100. The average index over all R and C for stratified, systematic, and random sampling is given in Table 3. Here we see that, generally, the variance index for systematic sampling is about the same as for stratified sampling with one observation per stratum. Both of these designs yielded much more precise estimates than random sampling.

Comparison of plot and plotless techniques

Both plotless techniques over-estimated the density of burrows in the grid (Table 4). The quadrats estimated accurately the actual density. The patterns were similar in both random and systematic sampling. In another portion of the colony (Table 5), the plotless techniques gave lower density estimates not significantly different ($p > 0.05$) from the transect techniques. However, all three techniques reflected the difference in burrow density between the two habitats.

Results from Triangle Island were more variable because, though all the techniques were compared in similar habitats, they were done in different locations within those habitats. We found marked differences between the techniques in which relative performance varied with the habitat (Table 6). Again Batcheler's techniques gave lower estimates than quadrats or transects, which showed similar results.

Discussion

In the colonies sampled, the largest gradient of density was from shore to inland. Density levels at a given distance from the shore tended to be more constant. This distribution gradient explains why density estimates derived from transects perpendicular to the shore were less variable than those derived from transects parallel to the shore. This follows from the sampling theory that in order to reduce the variability between them, transects should always be oriented across the density gradient. In this way, though variability within the transect from one end to the other may be great, variability between transects, and hence the variance, will be reduced.

Ideal quadrat sizes vary according to the distribution of the organisms to be counted. Kershaw (1975) indicated that in completely random distribution, all quadrat sizes were equally efficient in sampling, but that in clumped distribution the variance was influenced by quadrat size, being greater when quadrat size approximated mean clump size. However, sampling effort tends to be proportional to quadrat size. As we increase quadrat size, we reduce the number of quadrats that we can measure. We also increase the likelihood of missing burrows, especially in heavy vegetation (Harris and Murray 1981). Results here indicate that small quadrats provided a more precise estimate of density. This follows because with small quadrats the areas chosen for the sample were spread more over the colony and, because there were gradients of burrow density, we had a better chance of obtaining a representative sample. There is, however, a lower limit to quadrat size. Edge problems increase with a decrease in quadrat size, and subjective judgements as to whether a given burrow is inside or outside the quadrat may produce a significant bias.

When gradients are present, systematic sampling is generally more precise because it tends to sample the population more uniformly than random sampling, which is often difficult to apply in the field. However there are two weaknesses in systematic sampling: (1) it provides estimates with very high variances if there are serial patterns in the distribution of burrows, and (2) it does not offer unbiased procedures for estimating the variance.

Bourdeau (1953) indicates that sometimes the sacrifice in precision when using random sampling is compensated for by the possibility of soundly assessing the error of sampling. Kingsley and Smith (1981) indicate that in many instances an upper limit on the precision can be estimated for systematic procedures.

Quadrats and transects provided accurate estimates of burrow densities, whereas the point-quarter and Batcheler's methods tended to over-estimate density. Elsewhere, plotless techniques have been shown to over-estimate uniformly spaced populations and to under-estimate clumped ones (Cottam and Curtis 1956, Pielou 1959, Batcheler 1971). They are designed for sampling random or mildly clumped populations.

Conclusions

(1) In this study, orienting the transects roughly perpendicularly to the shoreline proved to be the most efficient method. This is because the highest density gradients were in this direction.
(2) When little effort is needed to locate plots and move between them, small quadrats are to be preferred to large ones. If the terrain were more difficult to traverse, an optimum plot size would make smaller plots less efficient.

(3) Plotless techniques should be used cautiously until more work is done on their performance in the field. In our study they gave biased results.
(4) A systematic sampling scheme proved to be at least as precise as a stratified scheme, and would involve much less work because strata would not have to be delineated.
(5) The advantages of random sampling over systematic sampling are:
(a) approximately unbiased estimates of precision and hence better potential for inference, and
(b) no possibility of a regular variation in population density corresponding to the sampling pattern.
(6) The advantages of systematic sampling over random sampling are:
(a) because there are generally large gradients in seabird nesting population densities, due to type of habitat, altitude, distance from the shore, etc., and because the possibility of the sampling interval in a systematic scheme corresponding to a regular variation in the population is remote, systematic sampling is much more precise than random sampling;
(b) it is also easier to locate sampling quadrats in the field by systematic rather than random sampling, and thus it has greater advantages in terms of precision per unit of effort than this paper may indicate.
(7) Overall, a systematic procedure proved to be more accurate and precise than a random sampling scheme or plotless techniques did.

Acknowledgements

We are grateful to D. Alcroft, D. Powell, and D. Bertram for their field assistance, and thank B. Foster for the authorization to work on the Anne Vallee Ecological Reserve, and the Canadian Coast Guard for providing accommodation on Pine Island. We also thank P. Whitehead for drafting the figures, and G. Kaiser, A. Gaston, B. Collins, and A. Diamond for their comments on earlier drafts of the manuscript.

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Table 1
Comparison of the precision of transects oriented perpendicular and parallel to shore

Orientation	n	Transect size (m)	Area sampled (m^2)	Burrow density (burr/ 100 m^2) ± SE*	Coefficient of variation (%)
Perpendicular to shore	6	1x150	900	62 ± 5	22
Parallel to shore	13	1x50	650	65 ± 10	57

* SE = Standard error.

Table 2
Sampling effort in relation to quadrat size

(a) Type I error = 0.05; type II error = 0.10

Quadrat Size (m)	Area (m^2)	CV* (%)	30% n	30% Area (m^2)	20% n	20% Area (m^2)	10% n	10% Area (m^2)
			Effort required to detect change of					
2x2	4	57	62	248	140	560	557	2228
4x4	16	39	29	464	66	1056	261	4176
8x8	64	28	15	960	34	2176	135	8640

(b) Type I error = 0.05 (i.e. 95% confidence limits)

Quadrat Size (m)	Area (m^2)	CV* (%)	30% n	30% Area (m^2)	20% n	20% Area (m^2)	10% n	10% Area (m^2)
			Effort required for confidence limits to be within % of mean					
2x2	4	57	14	56	32	128	125	500
4x4	16	39	7	112	15	240	59	944
8x8	64	28	4	256	8	512	31	1984

* CV = Coefficient of variation.

Table 3
Comparison of the precision of random and systematic samples, showing relative magnitude of variance

Quadrat size (m)	Sampling pattern: Stratified	Systematic	Random
2 x 2	34	16	51
4 x 4	30	24	47
8 x 8	18	27	56
2 x 4	31	21	48
2 x 8	25	26	49
4 x 8	23	27	50
2 x 40	29	7	64
4 x 40	21	21	58
8 x 40	24	27	49
Average	26	22	52

Table 4
Comparison of plot and plotless techniques in the Pine Island grid*

Method	Quadrat (2 x 2) n=100	Point-centred n=90	Batcheler's n=90
	Density estimate of Rhinoceros Auklets' burrows/100 m^2 ± SE†		
Systematic	85 ±2	104 ±5	119 ±19
Random	85 ±4	105 ±5	128 ±18

* Total count of the grid gave 85 burrows/100 m^2.
† SE = Standard error.

Table 5
Comparison of plot and plotless techniques in two habitats on Pine Island

Habitat	Transect†	Point-centred‡	Batcheler's‡
	Rhinoceros Auklet (no. of burrows/100 m^2) ± SE*		
A	54 ± 4	48 ± 6	50 ± 4
B	98 ± 8	81 ± 8	82 ± 16

* SE = Standard error.
† n=6, each 50 m long.
‡ n=23 sampling points.

Table 6
Comparison of quadrats, transects, and Batcheler's techniques in different habitats of Triangle Island

Habitat	Batcheler's* Unadjusted	Batcheler's* Adjusted	Quadrat†	Transect‡
	Density estimate (burrows/100 m^2), Cassin's Auklet			
A	256 ± 59 n = 26	290 ± 59 n = 26	428 ± 21 n = 25	325 ± 20 n = 3
B	11 ± 3 n = 26	14 ± 3 n = 26	135 ± 20 n = 25	184 ± 25 n = 5
C	81 ± 5 n = 24	47 ± 5 n = 24	142 ± 19 n = 25	118 n = 1
D	75 ± 4 n = 17	38 ± 4 n = 17	146 ± 17 n = 25	136 n = 1
E	121 ± 5 n = 24	60 ± 5 n = 24	96 ± 15 n = 25	102 n = 1

* See Batcheler (1973).
† 1 m^2 square quadrat.
‡ 2 x 50 m transect.